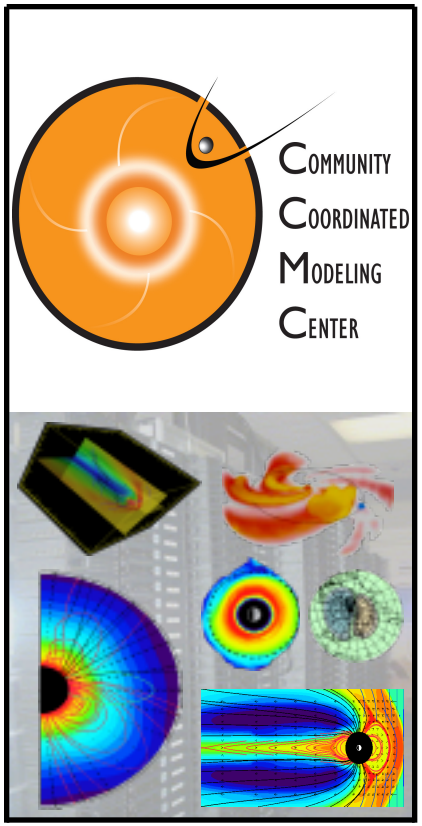


Quantifications of Geomagnetic Storm Impact on TEC and foF2 during March 17, 2013 event

Ja Soon Shim[1*], Ioanna Tsagouri[2], Larisa Goncharenko[3]
M. Leila Mays[1], Aleksandre Taktakishvili[1], Lutz Rastaetter[4], Maria M Kuznetsova[4]
Modelers: Ionosphere/Thermosphere Models hosted at Community Coordinated Modeling Center

1. CUA/NASA GSFC, Greenbelt, MD, USA,
2. National Observatory of Athens, Greece
3. MIT Haystack Observatory, Westford, MA. USA
4. NASA/GSFC, Greenbelt, MD, USA,

NASA Goddard Space Flight Center **http://ccmc.gsfc.nasa.gov**

Outline

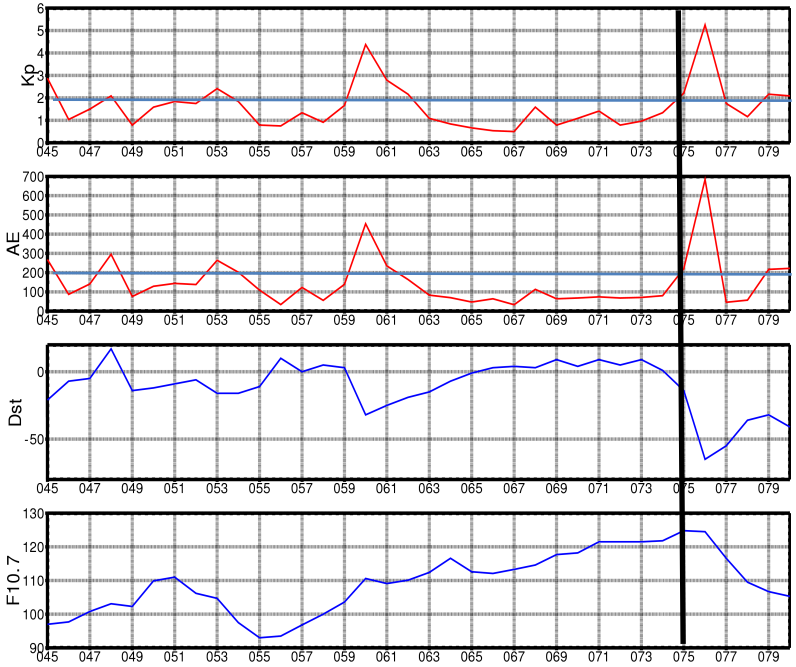
- Quantification of storm impact
  - Quiet-time background references
  - foF2 and TEC changes
  - Model/data comparison
- Impacts of uncertainty in the IMF on TEC simulation
- Summary

TEC and foF2 at 10 Ionosonde Stations

- 4 stations from US, 4 from Europe and 2 from South America to investigate:
  - latitude and local time dependence
  - hemispheric asymmetry
- Observations:
  - foF2 data from the Global Ionosphere Radio Observatory (GIRO)
  - GPS vertical TEC data from MIT Haystack Observatory (error < 4TECU)

Quiet-time References

- **One day before storm onset**
- Five consecutive days before storm onset
- Five quietest days within 30 days prior to storm
- 30 days prior to storm



daily averaged Kp, AE, Dst, and F10.7

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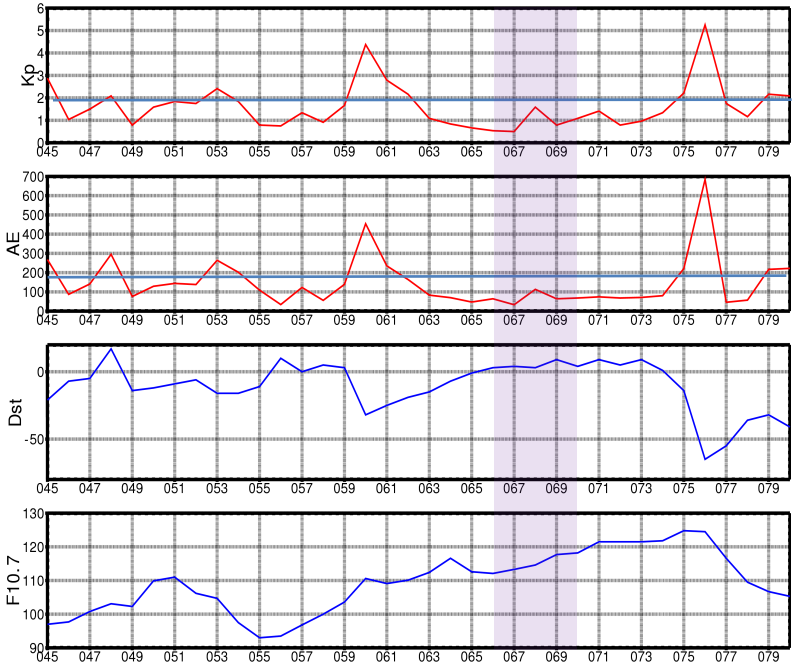

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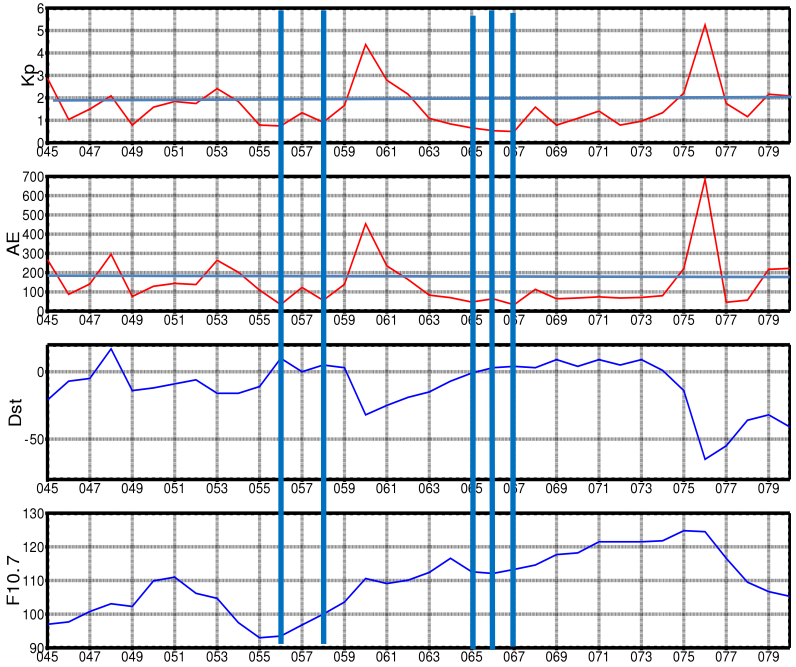

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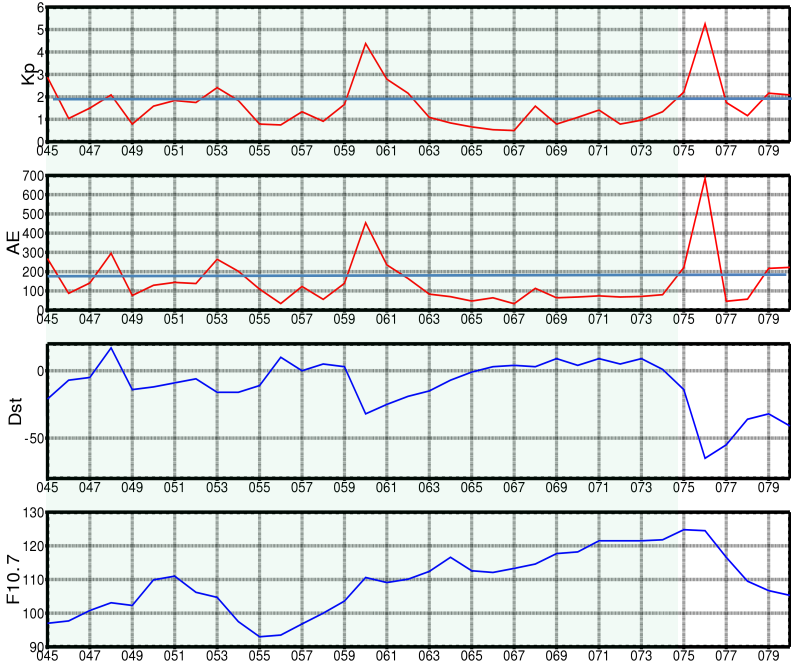
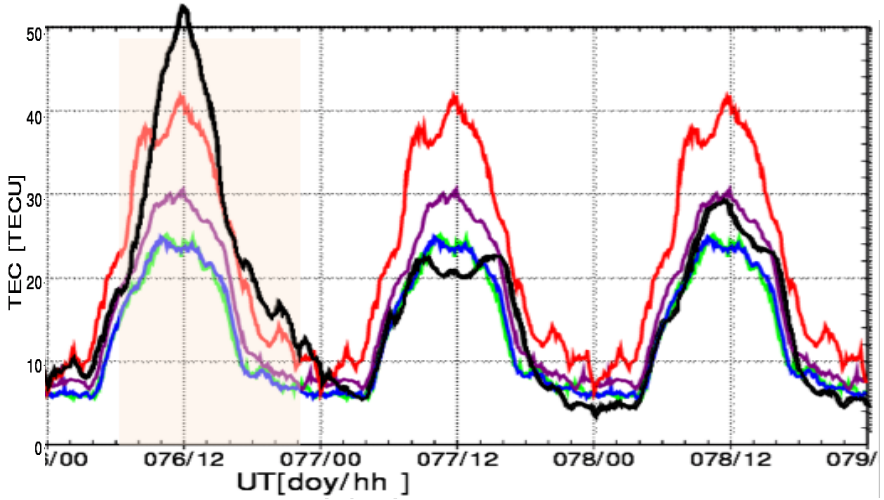


daily averaged Kp, AE, Dst, and F10.7

TEC: Comparison of Four Backgrounds

Athens (23.5E, 38.0N)



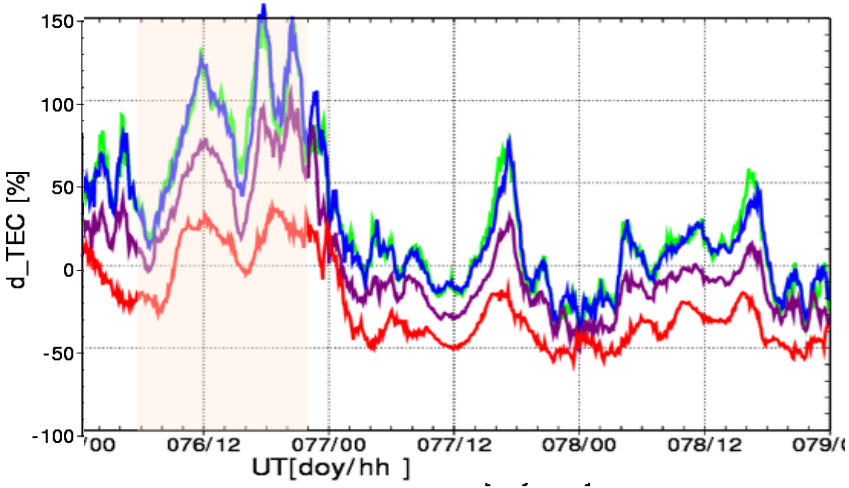
- The backgrounds are repeated across 3 days of the storm event.
- TEC on one day prior to the storm (red line) is larger than other references.
- 30-day median (green) and mean of the 5 quietest days (blue) are more suitable (difference < 1 TECU)

- Ionosphere-thermosphere model simulations also show similar features (not shown here).

TEC Changes

with respect to the four different backgrounds

dTEC Athens (23.5E, 38.0N)



- dTEC=100*(TEC – TEC_q)/TEC_q, where TEC_q = quiet time back ground
- Difference in TEC changes between red and blue (or green) appears more than 100 % .
- 30-day median (green) and mean of 5 quietest days (blue) are more suitable.

foF2 changes during the main phase

Station	dfoF2 > 20%						dfoF2 < -20%					
	Start Time		Max	t_max		Duration	Start time		Min (%)	t_min		Duration
	UT	LT	(%)	UT	LT	(hrs)	UT	LT		UT	LT	(hrs)
Europe												
Chilton	18.2	18.2	**24%**	**18.2**	**18.2**	0.3						
Pruhonice	11.0	12.0	**46%**	**11.8**	**12.8**	3.3						
Ebre	11.75	12.75	**97%**	**23.0**	**0.0**	8.3	6.75	7.75	-31%	7.7	8.7	2.7
Athens	11.5	13.5	**83%**	**22.8**	**0.8**	7.3						
North America												
Idaho Nat. Lab							7.5	0.5	**-45%**	**9.5**	**2.5**	11
Boulder							9.5	2.5	**-45%**	**16.0**	**16.0**	16
Millstone Hill							7.8	2.8	**-48%**	**9.3**	**4.3**	6.7
Eglin AFB							15.4	9.4	**-31%**	**15.8**	**9.75**	1
South America												
Jicamarca												
Port Stanley	19.5	15.5	**58%**	**19.5**	**15.5**	4.5						

dfoF2 = (foF2 –foF2_med)/foF2_med *100

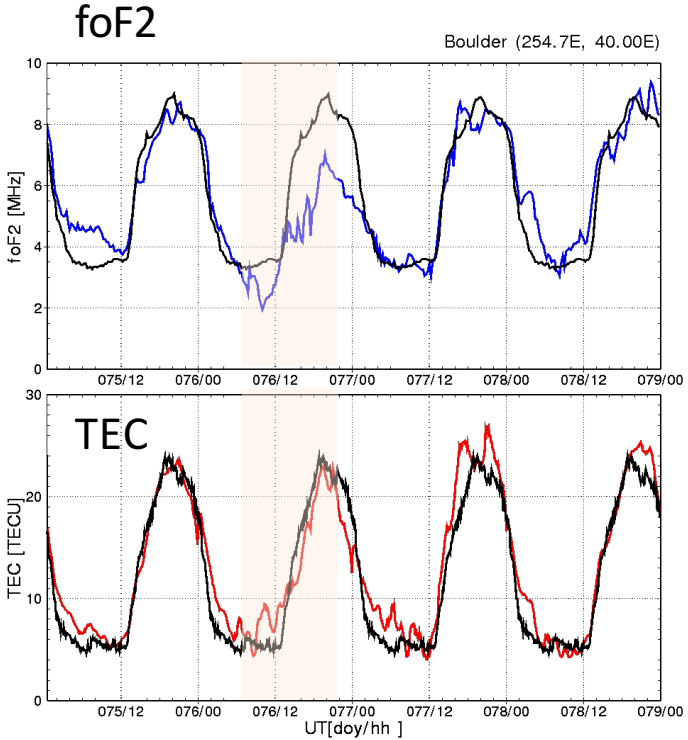
- A few hours after storm onset:
  - European sector in the daytime: positive effects due to increases in ionization
  - North America in the post-midnight sector: negative storm effects caused by the neutral composition disturbance (*Prölss,* 1993)

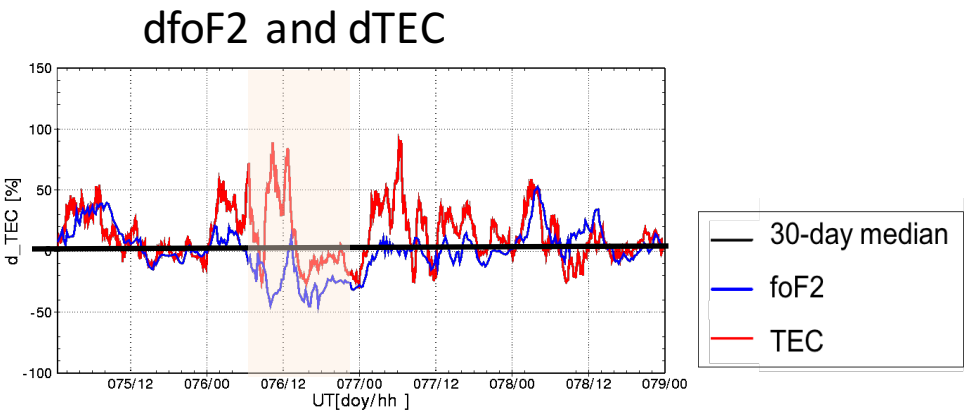
TEC changes during the main phase

Station	dTEC > 50%						dTEC < -40 %					
	start time		Max[%]	t_max		duration (hrs)	Start time		Min[%]	t_min		duration (hrs)
	UT	LT		UT	LT		UT	LT		UT	LT	
Europe												
Chilton	10.6	10.5	91.6%	11.5	11.5	2.8	20.2	20.1	-59.1%	11.5	11.5	1.6
Pruhonice	8.8	9.7	123.4%	11.4	12.4	5.8						
Ebre	9.6	9.6	144.5%	19.9	20.0	10.7						
Athens	8.3	9.8	148.9%	17.3	18.8	13.7						
North America												
Idaho Nat. Lab.	9.1	1.6	209.3%	11.8	4.3	5.2						
Boulder	9.5	2.5	89.4%	10.3	3.3	3.0						
Millstone Hill	10.5	5.7	75.1%	19.5	14.7	3.2	9.1	4.3	-43.7%	19.5	14.7	0.3
Eglin AFB	11.0	5.2	*89.6%*	*19.0*	*13.2*	*2.6*						
South America												
Jicamarca	8.7	3.5	232.2%	8.9	3.8	5.1	8.3	3.1	-43.1%	8.9	3.8	0.1
Port Stanley	17.0	13.1	***270.7%***	***20.3***	***16.4***	***2.8***						

- Same color depicts similar latitudes and it shows similar responses to the storm.
- Both foF2 and TEC responses to the storm are positive phase in European sector.
- Noticeable difference between the foF2 and TEC response in North America sector:
  - TEC shows mainly positive effects, while foF2 shows negative effects.
- TEC enhancement at Port Stanley (42S) is about three times larger than that at Eglin (40N).
- At Jicamarca, foF2 changes < |20%|, but TEC change goes up to 230%.

foF2 and TEC at Boulder





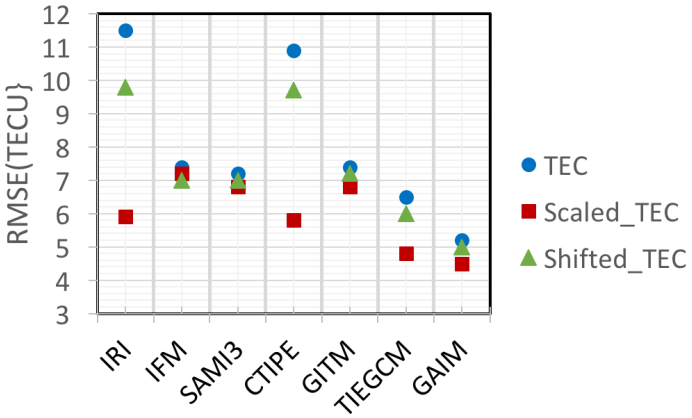
- during the main phase,
  - dfoF2 < 0
  - dTEC > 0 : contribution from plasmasphere

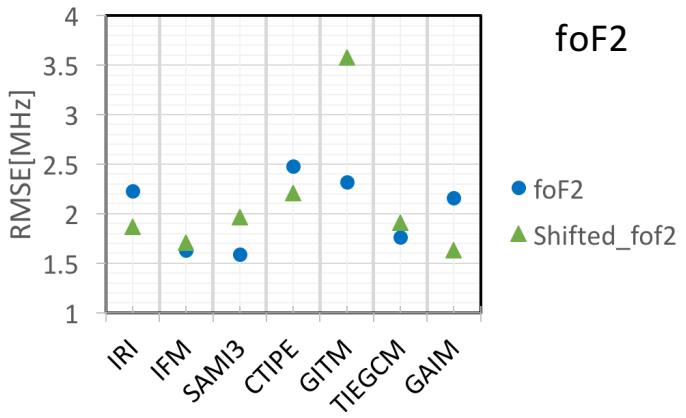
Assessment of Model Prediction

Model	Model Setting Description/Modelers	Lower and Upper boundary for TEC calculation (km)	
Empirical Model			
IRI 2012	IRI-2012 using IRI-corr model for topside Ne and using CCIR (International Radio Consultative Committee) for F-peak plasma frequency foF2, Dieter Bilitza (GMU, NASA/GSFC)	~60	~2,000
Physics Based Ionosphere Model			
IFM	IFM driven by F10.7 and Kp, Robert W. Schunk et al. (USU)	~90	~1,400
SAMI3	SAMI3 with the neutral wind model HWM93, Joseph Huba et al. (NRL)	~90	~2,000
Physics-based Coupled Ionosphere-Thermosphere Model			
CTIPE	CTIPe3.2 driven by Weimer [2005], Timothy Fuller-Rowell et al. (NOAA SWPC)	~140	~2000
GITM	GITM 2.3 driven by Weimer 2005, Aaron Ridley et al. (UM)	~90	~600
TIE-GCM	TIE-GCM2.0 driven by Weimer [2005], R. G. Roble et al. (HAO, NCAR)	~90	~600
Physics-based Data Assimilation Model			
USU-GAIM	USU-GAIM2.4.3 with GPS TEC observations from up to 400 ground stations (-60° < lat < 60°), Robert W. Schunk et al. (USU)	~90	~1,400

RMSE

TEC





foF2

- Average RMSE for 10 and 6 stations for TEC and foF2, respectively
- Scaled TEC = TEC*(Obs_med/TEC_med)
- Shifted TEC = TEC –min(TEC_med)
- Degree of Improvement of predicting performance by scaling depends on models.
- Averaged GPS TEC error < 2 TECU
- 3 TECU <TEC RMSE < 12 TECU
- 1.6 MHz < foF2 RMSE < 3.6 MHz

Ratio of Changes

Model	dfoF2>20%		dfoF2<-20%		dTEC > 50 %		dTEC < -40 %	
	ratio_max	dt_max	ratio_min	dt_min	ratio_max	dt_max	ratio_min	dt_min
IFM	0.99	8.25	0.71	2.95	1.5	4.6	1.2	1.9
SAMI3	0.92	4.50	1.84	2.38	2.0	6.3	1.5	1.6
CTIPE	2.54	0.00	0.78	2.67	0.5	3.6	1.2	2.3
GITM	2.42	1.00	0.60	2.12	3.7	3.9		
TIE-GCM	0.97	3.5	1.24	2.92	0.8	4.6		1.1
USU-GAIM	0.84	0.88			0.9	3.1	1.3	2.4

where, ratio_max =dfoF2_max_model/dfoF2_max_obs
(or dTEC_max_model/dTEC_max_obs)

dt_max=|t_max_obs - t_max_mod|
dt_min=|t_min_obs - t_min_mod|

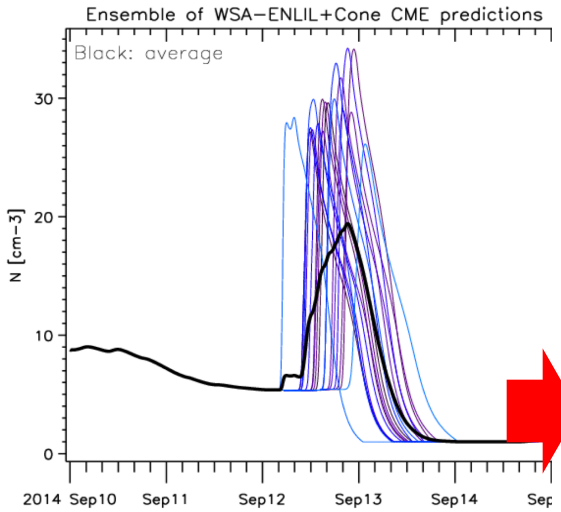
- Differences in ratio_max (and dt_max) among models are larger than those in ratio_min (and dt_min).
- Red: better ratio
- Blue: better time prediction

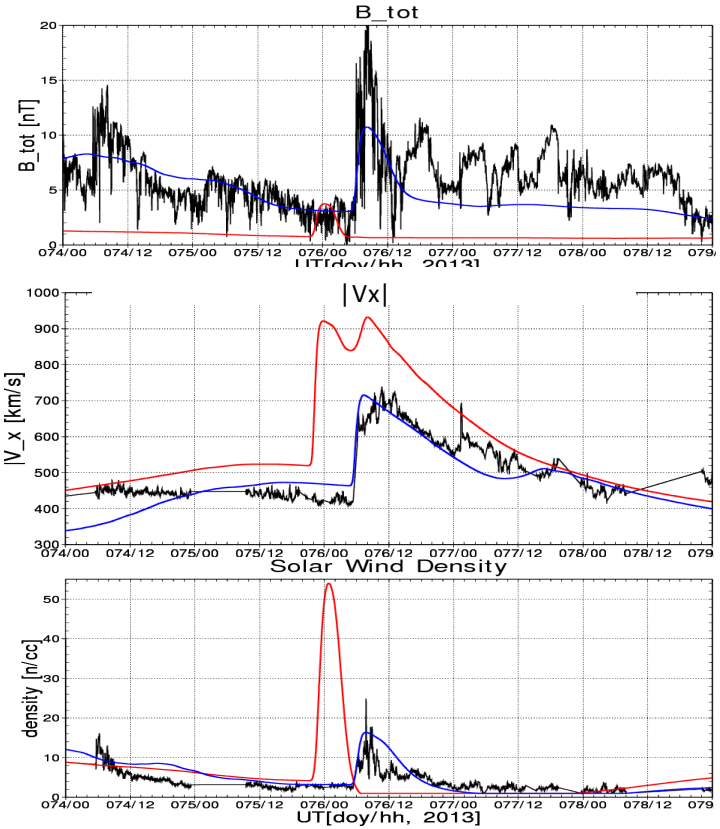
Impacts of Uncertainty

In the Interplanetary Magnetic Field (IMF)

on TEC

Solar Wind Parameters from Ensemble of WSA+ENLIL+Cone Model runs





— ACE data

— predicted mean value out of ensemble (generated before the event)

— best fit out of ensemble (after the event)

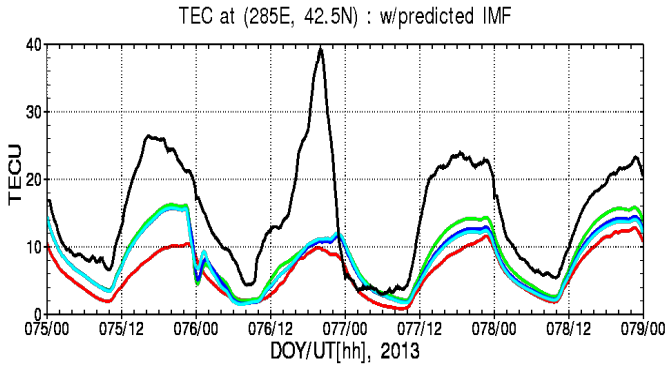
Shock arrival time:

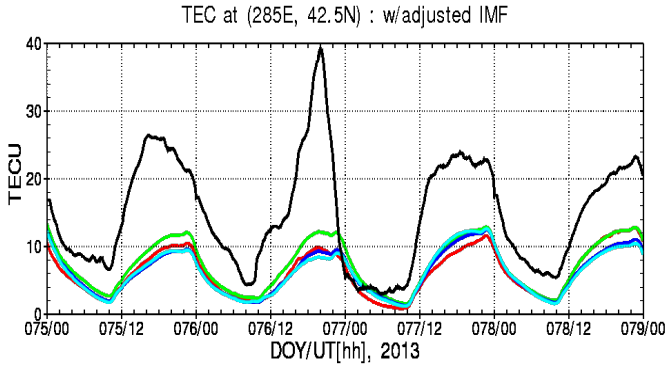
- predicted: 2013-03-16T21:34Z
- adjusted: 2013-03-17T05:12Z
- about 7 hour difference

IMF Clock angle ensemble of IT model runs: 90°, 135°, and 180°

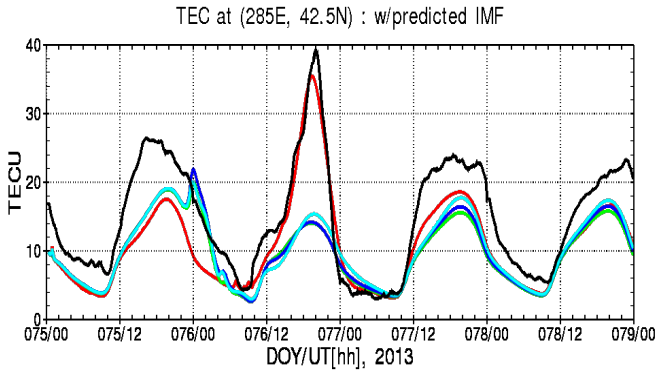
IMF Clock Angle Ensemble

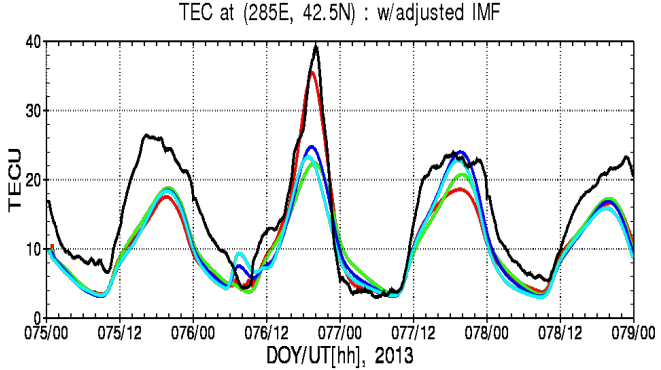
CTIPe





TIE-GCM





GPS vTEC
w/ ACE
w/ ENLIL (90°)
w/ ENLIL (135°)
w/ ENLIL (180°)

- Uncertainty in IMF clock angle (w/ adjusted solar wind parameters) has noticeable impact on TEC in mid latitude region during the main phase.

Summary

- Quantified storm impacts on foF2 and TEC at 10 selected ionosonde locations.
- Compared four different quiet-time references:
  - 30-day median and mean of five quietest days are comparable.
  - averaged 5 consecutive days and one day before the storm may not be suitable.
- During main phase,
  - European sector: both foF2 and TEC response to the storm are positive phase
  - North America sector: foF2 shows negative effects, while TEC shows positive response. It is possibly due to plasmasphere contribution.
  - TEC enhancement at Port Stanley (42S) is about three times larger than that at Eglin (40N).
- Evaluated how well Ionosphere-thermosphere models reproduce the TEC and foF2 changes during the main phase.
  - RMSE of the models is larger than errors in observations.
  - performance depends on metrics and quantities selected.
- Uncertainty in IMF clock angle has noticeable impact on TEC in mid latitude region during the main phase.